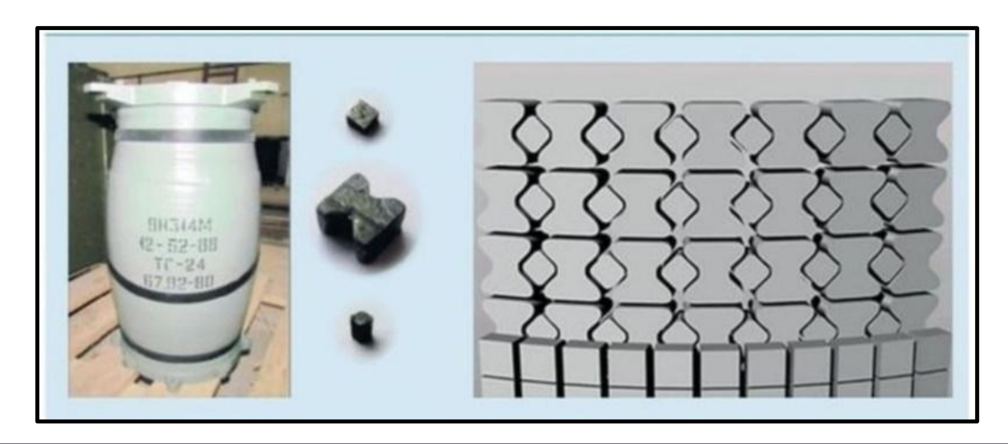
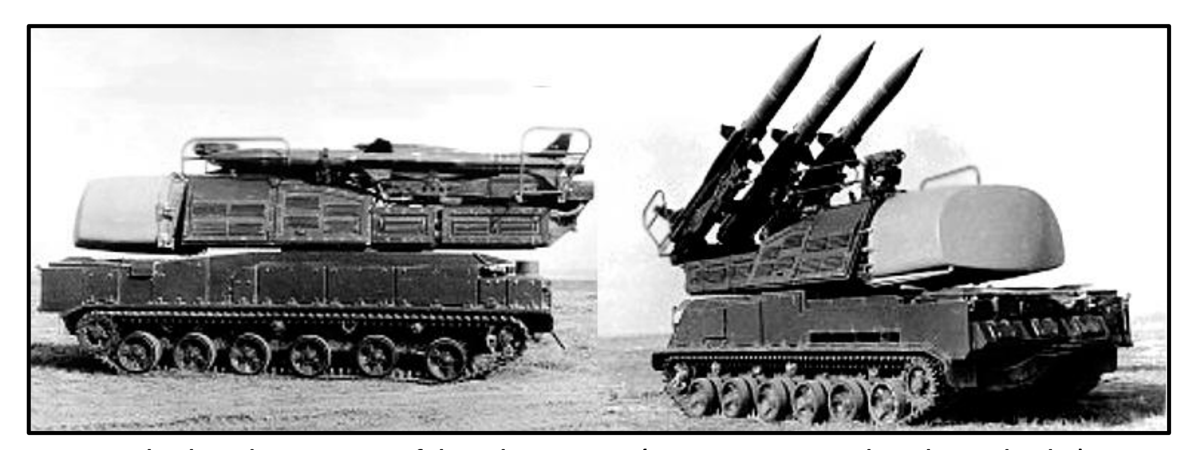
9K37M1 Buk-M1, 9K37M1-2 Buk-M1-2 (SA-11 Gadfly)
9K317 Buk-M2, 9K317M Buk-M3 (SA-17 Grizzly)

Buk was the first joint naval and army air defense SAM system which was designed ground up[1] for both branches of the armed force from the beginning. Regardless of the very strong political pressure the army disliked and resisted to accept it. The navy wanted a new type of SAM system against massive ASM low level/sea skimming (AGM-84 Harpoon) with lots of target channels while the army wanted to have an effective long range missile against the A-10 Thunderbolt II. The design requirement of the army caused lots headache for designers concerning on the warhead. Finally with butterfly shaped pre-formed shrapnel was proven to be enough effective for both roles. The anti-ship missiles (ASM) are soft comparing to A-10 but are much smaller while the A-10 is larger and harder target.



As we can see later for Buk-M1 the minimal engagement altitude is 15 meter but AGM-84 Harpoon can fly below this level. For the missile the performance of the proximity fuse has to be considered which maximal sensitivity is 20 meter. This makes possible to shoot down AGM-84 ASMs flying at 10-15 meter. The missile approaches above the target therefore the surface of the water is not a problem.

Even in the era of S-75M Volkhov was a priority the reducing the sensitivity the proximity fuse to achieve smaller minimal engagement altitude but despite lots of efforts the minimal engagement altitude of the S-75M was only 100 m.



Technology demonstrator of the Kub-M4 TELAR (transporter erector launcher and radar).

Before the development of the Buk the conception of it partially manifested as the proposed 2K12 Kub-M4 variant in 1978. The M4 variant kept the chassis of the Kub as well as the missiles but the missile launcher

[1] *Many other SAM systems used by both the army and the navy see in later chapter.*

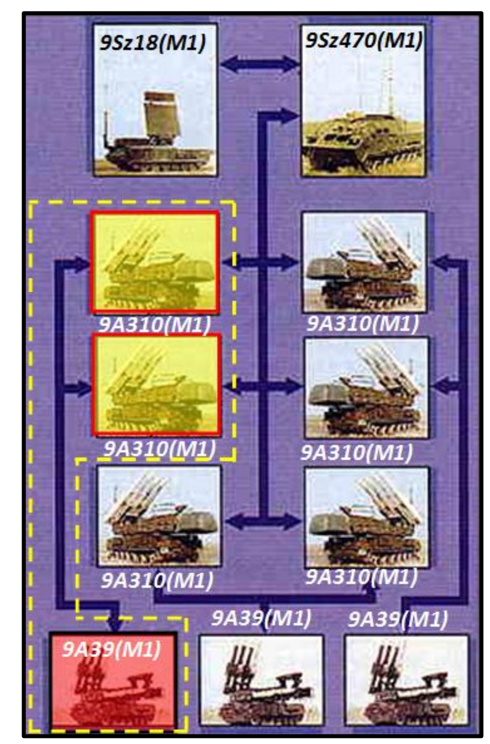
(TEL, transporter erector launcher) was converted to a TELAR (transporter erector launcher and radar) using the 9S35 (Fire Dome) fire control antenna system. With this major change the new TELAR could use the 3M9 type missiles of the 2K12 Kub (SA-6) as well as the new 9M38 missile of the new Buk system (upward compatibility) on the radar of the TELAR instead the SURN of 2K12. The available missile per launcher remained three.

The 2K12 Kub-M4 never entered into production neither the early 9K37-1 Buk-1 variant. In early stage of the development the idea was the 9A38 SOU (TELAR) was assigned to a 2K12 Kub battery. This addition increased the target channels two from one (1x1S91 SURN + 1x9A38 SOU) per battery and quantity of the missiles is increased four with larger engagement range. The new TELAR was designed to use the missiles of the older Kub system as well as the new missiles (backward compatibility).

The conception of Buk-1 was rejected and the 9K37M1 Buk-M1 proposition was accepted in 1983. The first full Buk-M1 brigade entered in service in about end of 1986 or early 1987. The Buk-M1 was designed to a higher level air defense than Kub. The Buk-M1 is intended to replace the 2K11 Krug.

A 9K37 Buk-M1 brigade has four battalions the main units of the battalions are on the image right. Each battalion has three batteries. Vehicles of a single battery are marked with dashed line on right. (In total the brigade has 12 batteries).

The brigade has one the brigade command post (CP) vehicle the 9S52 Polyana-D4. The brigade CP is not on the image right because it is on higher level above all the batteries. The brigade CP coordinates the work of on front level besides being the CP of the Buk-M1 brigade.



Buk-M1 battalion with three batteries.

Each battalion has one Kupol 9S18(M1) target acquisition radar, one the 9S470(M1) battalion command post vehicle and three batteries.

Each battery has two 9A310(M1) SOU (TELAR) and one 9A39(M1) PZU (TEL). The TELAR has one target channel and four missiles, the TEL has eight missiles. Besides being as a fully functional launcher the TEL also functions as the loader or TELARs. On the diagram above is single with battalion CP, the Kupol target acquisition radar and the three batteries.





Above left is a 9A310M1 SOU (TELAR) on right is an 9A39M1 PZU (TEL) launcher and missile loader.

The Buk-M1 (as the rejected Buk-1) uses SARH guidance similarly to 2K12 Kub, the fire control radar uses continuous wave (CW) target illumination. In fact the Buk-M1 is a scaled up Kub with stronger and better jam resistant radar in addition with a larger and dual thrust rocket motor equipped missiles.

Thanks to the camera on the TELAR the Buk-M1 (is marked with red arrow above on the image) very likely is able to perform the same delayed CW target illumination as the Kub-M3 with 3M9M3 missiles. For optical tracking target coordinates are provided by the target acquisition radar of the battalion the 9S18M1 Kupol-M1. The nominal maximal detection range of the Kupol-M1 against fighter size targets is about 140 km. The battalion command post is the 9S470M1.





Above left is a 9S470M1 battalion command post on right is the 9S18M1 Kupol-M1 target acquisition radar (SOC). On both vehicle is the typical antenna for the digital datalink which provides the connection within the battalion and between the 9S52 Polyana-D4 brigade command post.

The brigade command post of the Buk-M1 function as the CP of the unit but it is also serves as top level (front) IADS element in army air defense. The 9S52 Polyana-D4 is more or less comparable to VS-11 Vozduh but is a fully mobile. It can distribute data and establish connection not only between the battalions of the Buk-M1 but coordinates the work of the S-300V and Buk-M1 brigade moreover it able communicate with the Beriev A-50 AWACS airplane.





Above left the Polyana-D4 brigade command post, above right a picture from the inside the CP.

In a conflict between the NATO and Warsaw Pact Buk-M1 battalions very likely would deploy all along the frontline with overlapping engagement zone of the long range S-300V SAM system which demanded the better IADS connection and provided never seen before capabilities.

The appearance of the 9M38M1 missile is very similar to American RIM-66 Standard missile which is not so surprising because both missiles was designed to the same role, at least for the Russian navy. The maximal target speed of the system is 800 m/s, minimal target altitude is 15 meter, maximal altitude is 22 km. Minimal engagement range is 3 km the maximal is 35 km.

It is remarkable the missile 685 kg launch weight is almost identical with 3M9M3 missile of the 2K12 Kub while the engagement range is 60% larger and the warhead weight is increased to 70 kg from 57 kg. This huge leap forward is supported by the dual thrust rocket engine what provides better time-thrust characteristics for most of the trajectories. (Similar improvement was between the US-made AIM-7E and AIM-7F Air-to-Air missiles in range.) The average speed of the missile is about 850 m/s burnout speed is close to 1000 m/s.



The TELAR has only one target channel similar to Kub but also true is not limitation about the quantity of guided missiles because of the SARH guidance. With multiple launch is possible to increase the chance of a hit. Under the radome the TELAR is equipped with Cassegrain type radar antenna. The antenna is similar to the design of the radar of MiG-23 and MiG-29, see on the image right.

The Buk-M1 has anti-ARM capability as the Tor-M1. Against such type of targets the engagement zone is restricted and considerably smaller as well as the chance to hit (with one missile 0.9 against airplanes and 0.5 against ARMs and small cruise missiles, see later on the diagram). Officially Buk-M1 does not have ABM capability but Finnish crew during the final training on a live range exercise was able to shoot down the BM target imitator for the first attempt.

Comparing to the 2K11 Krug the capabilities and features of the Buk-M1 totally outclasses the predecessor system regardless a single battery has smaller engagement range. The defended airspace of the whole Buk-M1 brigade can be similar or even slightly larger but it the main difference is the maneuverability of the missiles as well the quantity of available target and missile channels. The anti-ARM capability just put the put the icing on the cake. A Buk-M1 brigade has 2.6 times more target channel and 3.5 times missile on rails than the 2K11 Krug had.

Brigade target channel quantity:

- 2K11 Krug: 3 battalion * 3 battery * 1 SNR 9
- 9K37M1 Buk-M1 4 battalion * 3 battery * 2 SOU 24

Brigade missile quantity on rails:

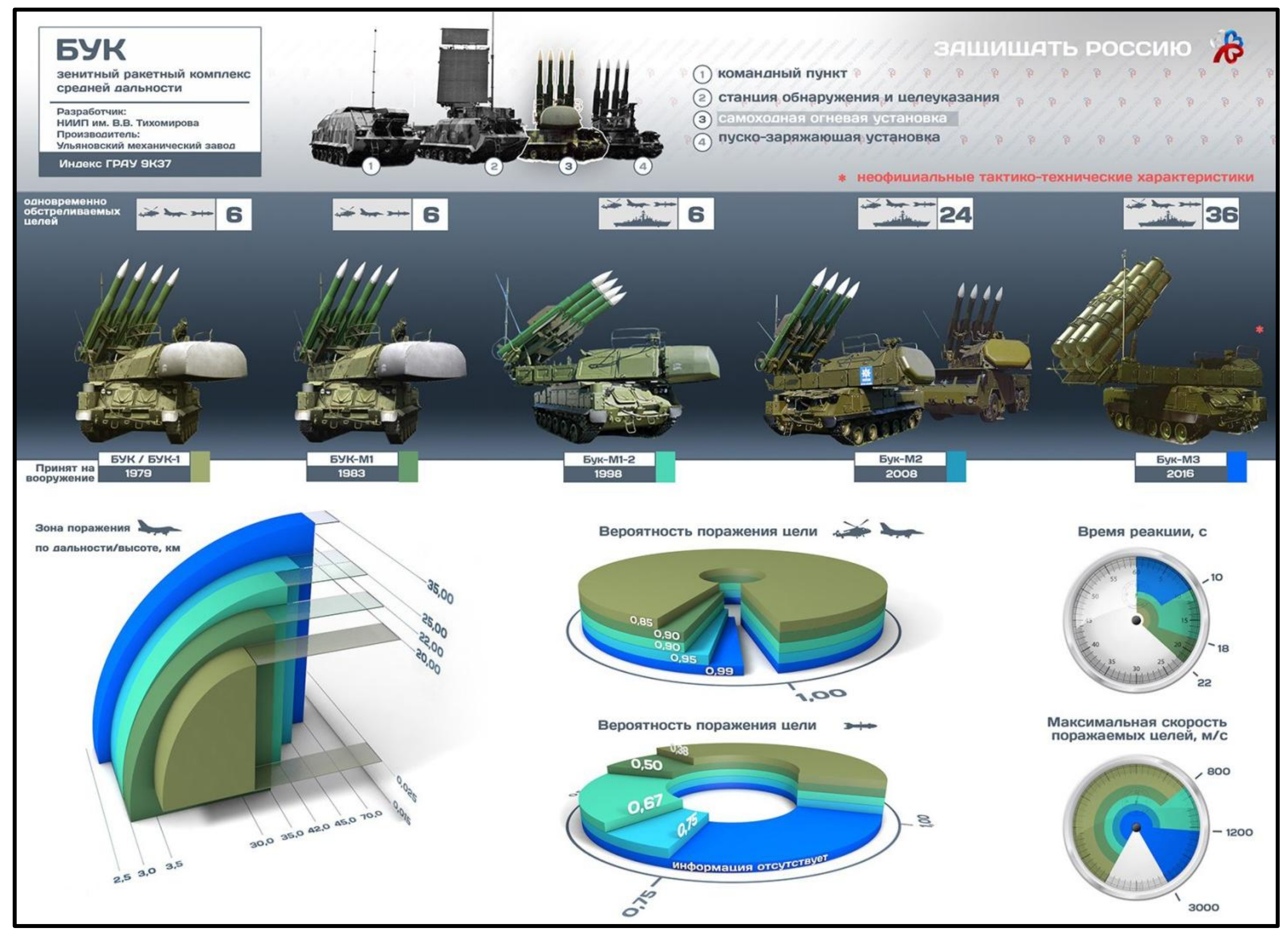
- 2K11 Krug: 3 battalion * 3 battery * 3 SPU * 2 missiles 54
- 9K37M1 Buk-M1 4 battalion * 3 battery *((3 SOU* 2 missiles)) + ((1 PZU* 8 missiles)) 192

Of course the further development on Buk family was unavoidable but comparing to upgrades on other army air defense systems the capability increase is much more serious. Even the base missile family, antenna type and guidance also were changed during the work. This was possible because of the modular structure of the Buk.



Main parameters of different Buk variants. What is interesting on the image the available target channels because on a later image Buk-M3 has 36 and not 24. This is maybe a typing error or just in the moment of the released material was not planned the ARH guidance. Maybe this is why M3 has the same value as M2.

From the Buk-M1-2 variant became available the 9M317 missile with slightly higher launch weight (720 kg) and the target speed increased to 1200 m/s. The minimal engagement altitude remained the same but the maximal distance increased from 35 km to 45 km, the maximal altitude from 22 km to 25 km. The maximal target speed makes more efficient against M3.0 top speed tactical ballistic missiles the M1-2. Of course against BMs the engagement zone is smaller only 20 km, maximal altitude in this case is 16 km. For ensuring the 90% or higher intercept success more than one missile is required.



Evolution of the Buk SAM family.

More serious upgrades were implemented for the 9K317 Buk-M2 and the 9K317M Buk-M3. Front the M2 variant the CW radar of the TELAR is discarded to a planar array electronically scanned radar. The system very likely uses the same guidance method as the Tor-M1/M2, radio command guidance until the terminal phase SARH guidance or exclusively SARH is also possible but not using CW illumination. Because of the rapid scan capable radar a single Buk-M2 TELAR has four target channels instead one of the Buk-M1. The number of available target channels are quadrupled. The firing arc of the TELAR is 90 degree. The range of the upgraded 9S18M1-3R (export variant) target acquisition radar increased to 150 km and the battalion CP vehicle is also the more advanced 9S510 type.

The Buk-M2 (as well as M3) has so many target channels which makes practically almost undefeatable with classical SEAD methods using only ARMs. The system has so many fire control radar – with 90 degree azimuth scan zone which means 90 degree firing arc – and so many target channels which makes hardly imaginable such a scenario where any opponent can launch enough AGM-88 or similar ARM.

Typically a fighter can carry two (F-16, Rafale, Tornado) or four (F-18E Super Hornet, Su-30 family, Eurofighter Typhoon) ARM considering reasonable weapon configuration. Because a single battalion has 3x90 degree firing arc and 4 target channels in any direction literally it is the only way to suppress or destroy the Buk-M2 launching more ARMs then total missile inventory of the system which is 48 missiles per battalion. We can judge how much effort is needed.

Of course the missiles of the Buk-M1/2/3 are not cheap therefore beyond a point economy is a factor. Is not necessarily has to shot down all incoming ARMs by the Buk. The slower but more numerous GBU-39/53 Small Diameter Bombs salvo also can be partially dealt by the Tor-M1/M2 or even the 2K22M Tunguska is able to this to save missile for larger range targets.



The changes and improvements of the Buk-M3 are even more impressive and radical. One of the major change is the totally new 9M317M missile (on the image left) which is also used by the naval Stihl-1 SAM system.[2] The new missiles are stored in canisters the rail type launcher is gone, the available missile for TELARs is increased to six.[3] The new missile can be SARH or ARH guidance, see later about the detailed explanation. The new 9M317 family still uses the butterfly shaped shrapnel what was developed for the M1 variant.

Thanks to the more optimal length/diameter ratio even with a lighter missile (581 kg) the engagement range is increased to 70 km, maximal target altitude is 35 km, maximal target speed is 3000 m/s which make possible to shoot down theatre ballistic missiles up to about 3000 km range. With the active radar guided missiles the target channels per battalion is increased to 36.

This design change is very likely the result of experiences of the operation Allied Force. During the operation NATO air force was able to suppress (but no fully destroy) with large scale use of AGM-88 the Serbian SAMs because the old SAMs had only single target channel. With ARH terminal guidance the emission time of the TELARs can be reduced moreover we can assume if appropriate datalink connection is available using TELARs is not necessary or just for very short periods. Therefore in some aspects the Buk-M3 with ARH guided missile is partially similar to NASAMS but with much large engagement zone and ATBM (Anti-Tactical Ballistic Missile) capability. (Or course Buk-M3 is much more expensive.)

The ATBM capability of the Buk-M3 means very likely it has full auto mode similar to S-350 Vityaz and the American Patriot SAM. We can safely assume this because even the much smaller Tor-M2 has full auto mode. The reaction time of the Buk-M3 is also improved from 15-18 second of the M1 version to 8-10 second.



Above left is the new TEL of the Buk-M3 the 9A316M with 12 missiles, above right is the new TELAR the 9A317M with 6 missiles in canisters.

The low level target detection and engagement capability also is increased by a new equipment. Similar to S-300P missile family the Buk-M3 can have a mast installed multi functional 9S36 Chair Back radar. The

[2] *It is bit funny that Buk-M1 started as a joint SAM system with strong opposition from the army and now the Buk-M3 also is a joint system with a new missile.*

[3] *It is quite interesting how long it took get rid of rails while the Osa-AKM, Tor-M1, Strela-10 and 2K22 Tunguska have stored their missiles in canisters since decades. The rail launched missile archaic design feature long lived in Buk family but finally got this upgrade.*

radar is able to illuminate targets for missile guidance and in case of need can perform sector search. The antenna is not rotatable only the direction (azimuth) setting of the mast can be changed.

The deployment time comparing to the 76N6 NVO (Clam Shell) low level target acquisition radar of S-300 is just a fraction because craning is not necessary, the 21 meter tall mast is set up with hydraulically driven pistons. The successful live fire trials of the Buk-M3 happened in 2015.



9S36 Chair Back radar during deployment phase, on the right is the Kupol target acquisition radar.

The main parameters of the Buk family by different variant is in the chart below:

Variant	*missile*	*weight*	*range*	*altitude*	*target speed*	*missile max. G*	*target channel per TELAR*
-	-	*kg*	*km*	*km*	*m/s*	*G*	*db*
9K37M Buk-M1 (SA-11)	9M38M	690	3-35	0,015-22	800	19	1
9K37M Buk-M1-2 (SA-11)	9M317	720	3-42	0,015-25	1200	30	1
9K317 Buk-M2 (SA-17)	9M317M	720	3-50	0,015-25	1200	30	4
9K37M Buk-M3 (SA-17)	9M317MA	581	3-70	0,015-70	3000	30 (?)	6

Target channel quantity of a Buk brigade depending on variant:

- 9K37M1 Buk-M1 4 battalion * 3 battery * 2 SOU (1) 24
- 9K317 Buk-M2 4 battalion * 3 battery * 2 SOU (4) 94
- 9K317M Buk-M3 4 battalion * 3 battery * 2 SOU (6) 144

Missiles ready to launch of Buk brigade depending on variant:

- 9K37M1 Buk-M1 4 battalion * 3 battery * (2 SOU * (4) + 1 PZU * (8)) 192
- 9K317 Buk-M2 4 battalion * 3 battery * (2 SOU * (4) + 1 PZU * (8)) 192
- 9K317M Buk-M3 4 battalion * 3 battery * (2 SOU * (6) + 1 PZU * (12)) 288

Hereby is short explanation to help understand the designation of the different type of the missiles.[4] Two different guidance (nose) section can be mounted. The 9E420 type has SARH guidance the 9V1103 (in Russian alphabet V = B) has ARH guidance. Missile with the SARH nose section has the letter 'A' in the designation. The letter 'E' means it is the export variant, the letter 'F' indicates the naval variant and the letter 'M' indicates canister loaded variant. These letters can be aggregated.

The following types exist according the source: 9M317, 9M317E, 9M317A, 9M317F, 9M317M, 9M317ME, 9M317MA, 9M317MAE, 9M317MF, 9M317MFE. The container/canister stored ARH guided missile of the Buk-M3 therefore is the 9M317MA in case of export variant 9M317MAE.

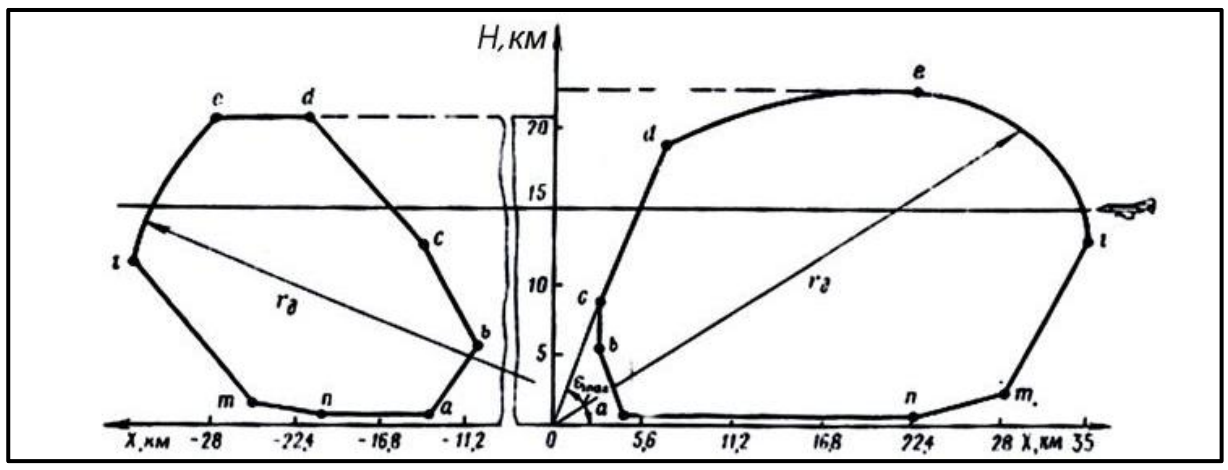
In short, the Buk-M1 and all the later variants represent a totally different level comparing to any other previous army or even PVO SAM systems. All variants have exceptionally lots of target channels and missiles but very likely the cost of the downside of the system. So far only a very few countries bought any variant of the Buk. Finland acquired just after the Cold War a small quantity of Buk-M1 in exchange of Soviet debt repayment and some ex-Soviet countries bought or inherited small quantity M1 or M2 variant besides Syrian M2 order. (Finland already have replaced Buk-M1.)

The first full Buk-M1 brigade entered in service in about end of 1986 or early 1987. Typically the most advanced new equipment appeared first in East Germany but in case of Buk-M1 the case was different and replaced a Krug brigade first in Hungary as army air defense of the Southern Group of Soviet Forces (SGSF) (Южная Группа Войск)

Finland acquired three Buk-M1 battalions in 1995 counting in today's cost for about 200 million Euro (850 M Finnish markka). Russian offered even the most advanced and long range S-300V but Finland found it too costly even they were amazed of its features. Russian offered also the S-300PMU battery for 700 million Finnish markka cost of each 5V55R missile was 3M Finnish markka.

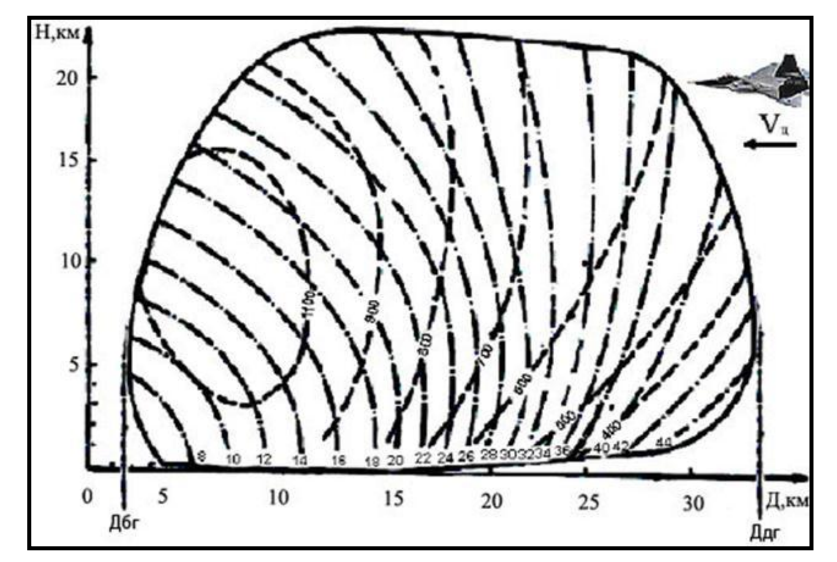
This pricing is a bit strange because the S-300PMU has only three radars (each are different type with longer range) but the missile quantity in both offer is almost the same. The three Buk-M1 battalions in total had 18 TELARS and three Kupol radars.

According to Finnish sources the radar and guidance technology of the Buk-M1 is similar to 2K12 Kub but in general is more advanced, they judged well the jam resistance of the Buk-M1.



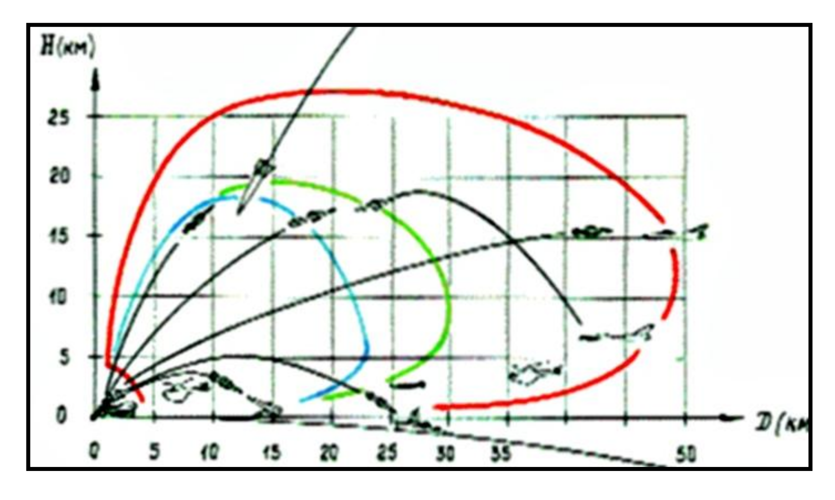
Engagement zone of the Buk-M1 with 0 km parameter (offset) distance against incoming (on left) and receding targets (on right.)

[4] https://vpk.name/library/f/9m317.html



Engagement zone of the Buk-M1 with 0 km parameter (offset) distance against incoming targets.

The parametric curves shows the missile flight time and maximal speed of the target.



Engagement zone of the Buk-M2 with 0 km parameter (offset) distance against incoming targets.

With blue color shows the zone against ballistic missiles, the blue against ARMs and the red against subsonic targets.

It is worth to compare the limits of the zone with the diagram above, the target speeds are correlates with the edges of different zones.

The Buk-M1 is quite similar to American AEGIS system which uses also many CW illuminators to establish more than one target channels per ship. On US ships are also separated target acquisition radar which assigns the target for CW illuminators.

As usual finally are some video and about the system:

- *http://www.ausairpower.net/APA-9K37-Buk.html*
- *https://www.youtube.com/watch?v=LSXMhaFntrU*
- *https://www.youtube.com/watch?v=t1LQWFul2UE*
- *https://www.youtube.com/watch?v=-ZCEXS_ZrzM&feature=youtu.be&t=1m23s*
- *http://nevskii-bastion.ru/buk-m3/*